Chapter 4
Reference Systems and Datum Transformations

4-1. Reference Systems

a. General. The discipline of surveying consists of locating points of interest on the surface of the earth. The positions of points of interest are defined by coordinate values that are referenced to a predefined mathematical surface. In geodetic surveying, this mathematical surface is called a datum, and the position of a point with respect to the datum is defined by its coordinates. The reference surface for a system of control points is specified by its position with respect to the earth and its size and shape. A datum is a coordinate surface used as reference figure for positioning control points. Control points are points with known relative positions tied together in a network. Densification of the network of control points refers to adding more control points to the network and increasing its scope. Both horizontal and vertical datums are commonly used in surveying and mapping to reference coordinates of points in a network. Reference systems can be based on the geoid, ellipsoid, or a plane. The physical earth's gravity force can be modeled to create a positioning reference frame that rotates with the earth. The geoid is such a surface (an equipotential surface of the earth's gravity field) that best approximates Mean Sea Level (MSL)--see Figure 4-1. The orientation of this surface at a given point on geoid is defined by the plumb line. The plumb line is oriented tangent to the local gravity vector. Surveying instruments can be readily oriented with respect to the gravity field because its physical forces can be sensed with simple mechanical devices. A mean gravity field can be used as a reference surface to represent the actual earth's gravity field. Such a reference surface is developed from an ellipsoid of revolution that best approximates the geoid. An ellipsoid of revolution provides a well-defined mathematical surface to calculate geodetic distances, azimuths, and coordinates. The major semi-axis (a) and minor semi-axis (b) are the parameters used to determine the ellipsoid size and shape. The shape of a reference ellipsoid also can be described by either its flattening (f) or its eccentricity (e).

Flattening: $f = (a - b) / a$

Eccentricity: $e = [\,sqrt(a^2 - b^2)\,] / a$

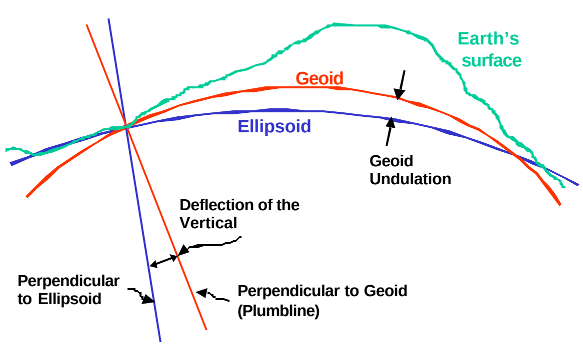

Figure 4-1. The relationship between the ellipsoid, geoid, and the physical surface of the earth

4-2. Geodetic Coordinates

a. General. A coordinate system is defined by the location of the origin, orientation of its axes, and the parameters (coordinate components) which define the position of a point within the coordinate system. Terrestrial coordinate systems are widely used to define the position of points on the terrain because they are fixed to the earth and rotate with it. The origin of terrestrial systems can be specified as either geocentric (origin at the center of the earth) or topocentric (origin at a point on the surface of the earth). The orientation of terrestrial coordinate systems is described with respect to its poles, planes, and axes. The primary pole is the axis of symmetry of the coordinate system, usually parallel to the rotation axis of the earth, and coincident with the minor semi-axis of the reference ellipsoid. The reference planes that are perpendicular to the primary pole are the equator (zero latitude) and the Greenwich meridian plane (zero longitude). Parameters for point positioning within a coordinate system refer to the coordinate components of the system (either Cartesian or curvilinear).

b. Geodetic Coordinates. Geodetic coordinate components consist of:

- latitude (ϕ),
- longitude (λ),
- ellipsoid height (h).

Geodetic latitude, longitude, and ellipsoid height define the position of a point on the surface of the Earth with respect to the reference ellipsoid.

(1) Geodetic latitude (ϕ). The geodetic latitude of a point is the acute angular distance between the equatorial plane and the normal through the point on the ellipsoid measured in the meridian plane (Figure 4-2). Geodetic latitude is positive north of the equator and negative south of the equator.

(2) Geodetic longitude (λ). The geodetic longitude is the angle measured counter-clockwise (east), in the equatorial plane, starting from the prime meridian (Greenwich meridian), to the meridian of the defined point (Figure 4-2). In the continental United States, longitude is commonly reported as a west longitude. To convert easterly to westerly referenced longitudes, the easterly longitude must be subtracted from 360 deg.

East-West Longitude Conversion:

$$\lambda\,(W) = [\ 360\ -\ \lambda\,(E)\ ]$$

For example:

$$\lambda\,(E) = 282^{d}\ 52^{m}\ 36.345^{s}\ E$$
$$\lambda\,(W) = [\ 360^{d} - 282^{d}\ 52^{m}\ 36.345^{s}\ E\ ]$$
$$\lambda\,(W) = 77^{d}\ 07^{m}\ 23.655^{s}\ W$$

(3) Ellipsoid Height (h). The ellipsoid height is the linear distance above the reference ellipsoid measured along the ellipsoidal normal to the point in question. The ellipsoid height is positive if the reference ellipsoid is below the topographic surface and negative if the ellipsoid is above the topographic surface.

(4) Geoid Separation (N). The geoid separation (geoidal height) is the distance between the reference ellipsoid surface and the geoid surface measured along the ellipsoid normal. The geoid separation is positive if the geoid is above the ellipsoid and negative if the geoid is below the ellipsoid.

(5) Orthometric Height (H). The orthometric height is the vertical distance of a point above or below the geoid.

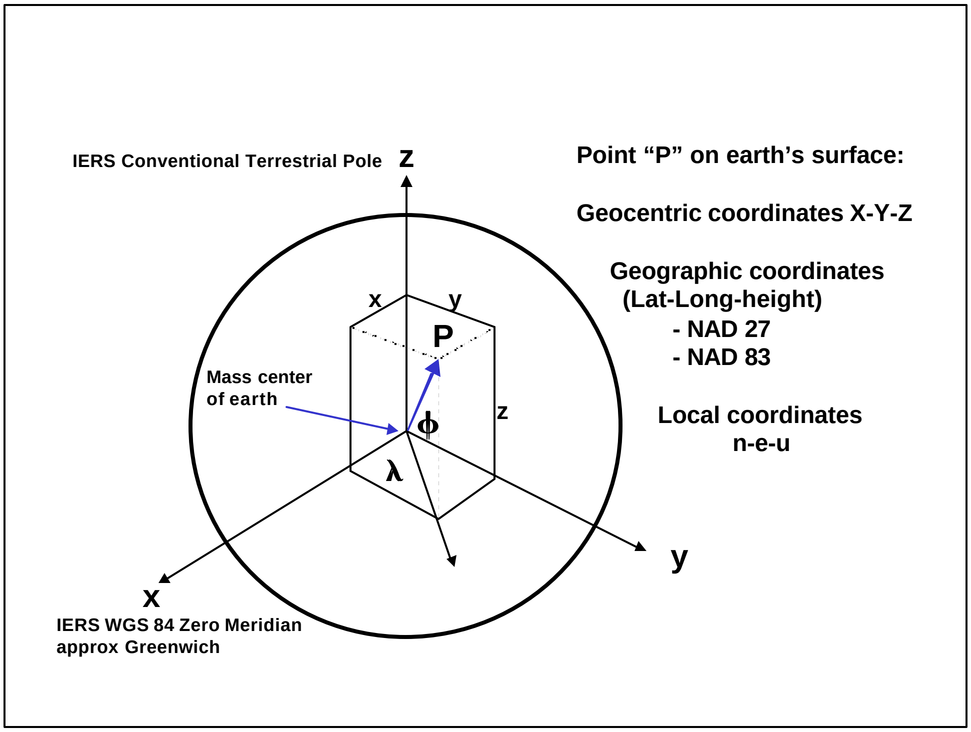

Figure 4-2. Coordinate reference frames

c. Datums. A datum is a coordinate surface used as reference for positioning control points. Both horizontal and vertical datums are commonly used in surveying and mapping to reference coordinates of points in a network.

(1) Horizontal Datum. A horizontal datum is defined by specifying: the 2D geometric surface (plane, ellipsoid, sphere) used in coordinate, distance, and directional calculations; the initial reference point (origin); and a defined orientation, azimuth or bearing from the initial point.

(a) Geodetic Datum. Five parameters are required to define an ellipsoid-based datum. The major semi-axis (a) and flattening (f) define the size and shape of the reference ellipsoid; the latitude and longitude of an initial point; and a defined azimuth from the initial point define its orientation with respect to the earth. The NAD 27 and NAD 83 systems are examples of horizontal geodetic datums.

(b) Project Datum. A project datum is defined relative to local control and might not be directly referenced to a geodetic datum. Project datums are usually defined by a system with perpendicular axes, and with arbitrary coordinates for the initial point, and with one (principal) axis oriented toward true north.

(d) NAD 27. NAD 27 is based on an adjustment of surveying measurements made between numerous control points using the Clarke 1866 reference ellipsoid. The origin and orientation of NAD 27 is defined relative to a fixed triangulation station in Kansas (i.e., Meades Ranch). Azimuth orientation for NAD 27 is referenced to South, with the Greenwich Meridian for longitude origin. The distance reference units for NAD 27 are in US Survey Feet. NAD 27 was selected for North America.

(e) NAD 83. NAD 83 is defined with respect to the Geodetic Reference System of 1980 (GRS 80) ellipsoid. GRS 80 is a geocentric reference ellipsoid. Azimuth orientation for NAD 83 is referenced to North with the Greenwich Meridian for longitude origin. The distance reference units for NAD 83 are in meters.

(f) WGS 84. WGS 84 is defined with respect to the World Geodetic System of 1984 (WGS 84) ellipsoid. WGS 84 is a geocentric reference ellipsoid and is the reference system for the Global Positioning System (GPS). Azimuth orientation for WGS 84 is referenced to North, with the Greenwich Meridian for longitude origin. The distance reference units for WGS 84 are in meters.

(2) Vertical Datum. A vertical datum is a reference system used for reporting elevations. Vertical datums are most commonly referenced to:

- Mean Sea Level (MSL),
- Mean Low Water (MLW),
- Mean Lower Low Water (MLLW),
- Mean High Water (MHW).

Mean Sea Level based elevations are used for most construction, photogrammetric, geodetic, and topographic surveys. MLLW elevations are used in referencing coastal navigation projects. MHW elevations are used in construction projects involving bridges over navigable waterways.

(a) The vertical reference system formerly used by USACE was the National Geodetic Vertical Datum of 1929 (NGVD 29). The North American Vertical Datum of 1988 (NAVD 88) should be used by USACE for all vertical positioning surveying work. Transformations between NGVD 29 and NAVD 88 have been developed for general use--refer to Appendix C for details.

4-3. State Plane Coordinate System

a. General. State Plane Coordinate Systems (SPCS) were developed by the National Geodetic Survey (NGS) to provide plane coordinates over a limited region of the earth's surface. To properly relate geodetic coordinates (ϕ-λ-h) of a point to a 2D plane coordinate representation (Northing, Easting), a conformal mapping projection must be used. Conformal projections have mathematical properties that preserve differentially small shapes and angular relationships as a result of the transformation between the ellipsoid and mapping plane. Map projections that are most commonly used for large regions are based on either a conic or a cylindrical mapping surface (Figure 4-3). The projection of choice is dependent on the north-south or east-west areal extent of the region. Areas with limited east-west dimensions and indefinite north-south extent use the Transverse Mercator (TM) type projection. Areas with limited north-south dimensions and indefinite east-west extent use the Lambert projection. The SPCS was designed to minimize the spatial distortion at a given point to approximately one part in ten thousand (1:10,000). To satisfy this criteria, the SPCS has been divided into zones that have a maximum width or height of approximately one hundred and fifty eight statute miles (158 miles). Therefore, each state may have several zones or may employ both the Lambert (conic) and Transverse Mercator (cylindrical) projections. The projection state plane coordinates must be referenced to a specific geodetic datum (i.e., the datum that the initial geodetic coordinates are referenced to must be known).

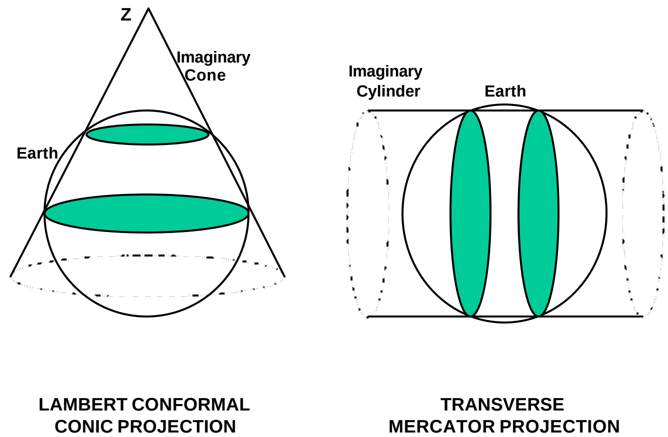

Figure 4-3. Common Map Projections

b. Transverse Mercator (TM). The Transverse Mercator projection uses a cylindrical surface to cover limited zones on either side of a central reference longitude. Its primary axis is rotated perpendicular to the symmetry axis of the reference ellipsoid. Thus, the TM projection surface intersects the ellipsoid along two lines equidistant from the designated central meridian longitude (Figure 4-4). Distortions in the TM projection increase predominantly in the east-west direction. The scale factor for the Transverse Mercator projection is unity where the cylinder intersects the ellipsoid. The scale factor is less than one between the lines of intersection, and greater than one outside the lines of intersection. The scale factor is the ratio of arc length on the projection to arc length on the ellipsoid. To compute the state plane coordinates of a point, the latitude and longitude of the point and the projection parameters for a particular TM zone or state must be known.

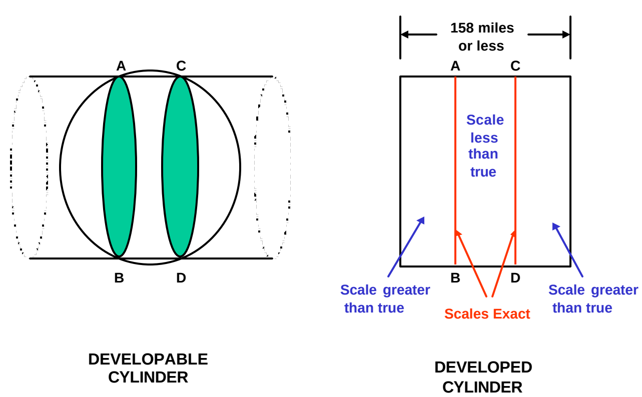

Figure 4-4. Transverse Mercator Projection

c. Lambert Conformal Conic (LCC). The Lambert projection uses a conic surface to cover limited zones of latitude adjacent to two parallels of latitude. Its primary axis is coincident with the symmetry axis of the reference ellipsoid. Thus, the LCC projection intersects the ellipsoid along two standard parallels (Figure 4-5). Distortions in the LCC projection increase predominantly in the north-south direction. The scale factor for the Lambert projection is equal to unity at each standard parallel and is less than one inside, and greater than one outside the standard parallels. The scale factor remains constant along the standard parallels.

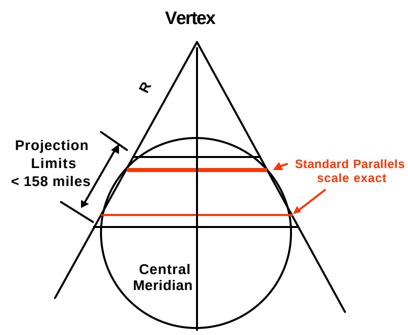

Figure 4-5. Lambert Projection

c. Scale units. State plane coordinates can be expressed in both feet and meters. State plane coordinates defined on the NAD 27 datum are published in feet. State plane coordinates defined on the NAD 83 datum are published in meters, however, state and federal agencies can request the NGS to provide coordinates in feet. If NAD 83 based state plane coordinates are defined in meters and the user intends to convert those values to feet, the proper meter-feet conversion factor must be used. Some states use the International survey foot rather than the US Survey foot in the conversion of feet to meters.

International Survey Foot:

1 International Foot = 0.3048 meter (exact)

US Survey Foot:

1 US Survey Foot = 1200 / 3937 meter (exact)

4-4. Universal Transverse Mercator Coordinate System

a. General. Universal Transverse Mercator (UTM) coordinates are used in surveying and mapping when the size of the project extends through several state plane zones or projections. UTM coordinates are also utilized by the US Army, Air Force, and Navy for mapping, charting, and geodetic applications. The UTM projection differs from the TM projection in the scale at the central meridian, origin, and unit representation. The scale at the central meridian of the UTM projection is 0.9996. In the Northern Hemisphere, the northing coordinate has an origin of zero at the equator. In the Southern Hemisphere, the southing coordinate has an origin of ten million meters (10,000,000 m). The easting coordinate has an origin five hundred thousand meters (500,000 m) at the central meridian. The UTM system is divided into sixty (60) longitudinal zones. Each zone is six (6) degrees in width extending three (3) degrees on each side of the central meridian. The UTM system is applicable between latitudes eighty-four degrees north (84^{d} N) to eighty degrees south (80^{d} S). To compute the UTM coordinates of a point, the TM coordinates must be determined. The UTM northing or southing (N_{UTM}, S_{UTM}) coordinates are computed by multiplying the scale factor (0.9996) at the central meridian by the TM northing or southing (N_{TM}, S_{TM}) coordinate values. In the Southern Hemisphere, a ten million meter (10,000,000 m) offset must be added to account for the origin. The UTM eastings (E_{UTM}) are derived by multiplying the TM eastings (E_{TM}) by the scale factor of the central meridian (0.9996) and adding a five-hundred thousand meter (500,000 m) offset to account for the origin. UTM coordinates are always expressed in meters.

UTM Northings, Southings, and Eastings

Northern Hemisphere:

$$N_{UTM} = (0.9996)\, N_{TM}$$

Southern Hemisphere:

$$S_{UTM} = (0.9996)\, S_{TM} + 10{,}000{,}000 \text{ m}$$

$$E_{UTM} = (0.9996)\, E_{TM} + 500{,}000 \text{ m}$$

The UTM zone (Z) can be calculated from the geodetic longitude of the point (converted to decimal degrees). In the continental United States, UTM zones range from ten (10) to nineteen (19).

UTM Zone:

$$Z = (180 + \lambda) / 6 \qquad \text{(east longitude)}$$

$$Z = (180 - \lambda) / 6 \qquad \text{(west longitude)}$$

where

Z = UTM zone number

If the computed zone value Z results in a decimal quantity, then the zone must be incremented by one whole zone number.

Example of UTM Zone Calculation:

$$\lambda = 77^{d}\ 08^{m}\ 44.3456^{s}\ W$$

$$Z = 17.14239$$
$$Z = 17 + 1$$
$$Z = 18$$

In the example above, Z is a decimal quantity, therefore, the zone equals seventeen (17) plus one (1).

4-5. Datum Transformations

a. General. Federal Geodetic Control Subcommittee (FGCS) members, which includes USACE, have adopted NAD 83 as the standard horizontal datum for surveying and mapping activities performed or financed by the Federal government. To the extent practicable, legally allowable, and feasible, USACE should use NAD 83 in its surveying and mapping activities. Transformations between NAD 27 coordinates and NAD 83 coordinates are generally obtained using the CORPS Convert (i.e., CORPSCON) software package or other North American Datum Conversion (i.e., NADCON) based programs.

b. Conversion techniques. USACE survey control published in the NGS control point database has been already converted to NAD 83 values. However, most USACE survey control was not originally in the NGS database and was not included in the NGS readjustment and redefinition of the national geodetic network. Therefore, USACE will have to convert this control to NAD 83. Coordinate conversion methods considered applicable to USACE projects are discussed below.

(1) Resurvey from NAD 83 Control. A new survey using NGS published NAD 83 control could be performed over the entire project. This could be either a newly authorized project or one undergoing major renovation or maintenance. Resurvey of an existing project must tie into all monumented points. Although this is not a datum transformation technique, and would not normally be economically justified unless major renovation work is being performed, it can be used if existing NAD 27 control is of low density or accuracy.

(2) Readjustment of Survey. If the original project control survey was connected to NGS control stations, the survey may be readjusted using the NAD 83 coordinates instead of the NAD 27 coordinates originally used. This method involves locating the original field notes and observations, and completely readjusting the survey and fixing the published NAD 83 control coordinates.

(3) Mathematical Transformations. Since neither of the above methods can be economically justified on most USACE projects, mathematical approximation techniques for transforming project control data to NAD 83 have been developed. These methods yield results which are normally within ± 1 foot of the actual values and the distribution of errors are typically consistent within a local project area. Since these coordinate transformation techniques involve approximations, they should be used with caution when real property demarcation points and precise surveying projects are involved. When mathematical transformations are employed they should be adequately noted so that users will be aware of the conversion method.

4-6. Horizontal Datum Transformations

a. General. Coordinate transformations from one geodetic reference system to another can be most practically made by using either a local seven-parameter transformation, or by interpolation of datum shift values across a given region.

b. Seven parameter transformations. For worldwide (OCONUS) and local datum transformations, the procedures referenced in USATEC SR-7 1996, "Handbook for Transformation of Datums, Projections, Grids and Common Coordinate Systems" should be consulted. This document contains references for making generalized datum shifts and working with a variety of commonly used map projections.

c. Grid-shift transformations. Current methods for interpolation of datum shift values use the difference between known coordinates of common points from both the NAD 27 and NAD 83 adjustments to model a best-fit shift in the regions surrounding common points. A grid of approximate datum shift values is established based on the computed shift values at common points in the geodetic network. The datum shift values of an unknown point within a given grid square are interpolated along each axis to compute an approximate shift value between NAD 27 and NAD 83. Any point that has been converted by such a transformation method, should be considered as having only approximate NAD 83 coordinates.

d. NADCON/CORPSCON. NGS developed the transformation program NADCON, which yields consistent NAD 27 to NAD 83 coordinate transformation results over a regional area. This technique is based on the above grid-shift interpolation approximation. NADCON was reconfigured into a more comprehensive program called CORPSCON. This software converts between:

NAD 27	NAD 83	SPCS 27	SPCS 83
UTM 27	UTM 83	NGVD 29	NAVD 88
GEOID96	HARN		

Technical documentation and operating instructions for CORPSCON are listed in Appendix B. Since the overall CORPSCON datum shift (from point to point) varies throughout North America, the amount of datum shift across a local project is also not constant. The variation can be as much as 0.1 foot per mile. Some typical NAD 27 to NAD 83 based coordinate shift variations that can be expected over a 10,000 foot section of a project are shown below:

Project Area	SPCS Reference	Per 10,000 feet
Baltimore, MD	1900	0.16 ft
Los Angeles, CA	0405	0.15 ft
Mississippi Gulf Coast	2301	0.08 ft
Mississippi River (IL)	1202	0.12 ft
New Orleans, LA	1702	0.22 ft
Norfolk, VA	4502	0.08 ft
San Francisco, CA	0402	0.12 ft
Savannah, GA	1001	0.12 ft
Seattle, WA	4601	0.10 ft

Such local scale changes will cause project alignment data to distort by unequal amounts. Thus, a 10,000-foot tangent on NAD 27 project coordinates could end up as 9,999.91 feet after mathematical transformation to NAD 83 coordinates. Although such differences may not be appear significant from a lower-order construction survey standpoint, the potential for such errors must be recognized. Therefore, the transformations will not only significantly change absolute coordinates on a project, the datum transformation process will slightly modify the project's design dimensions and/or construction orientation and scale. On a navigation project, for example, an 800.00 foot wide channel could vary from 799.98 to 800.04 feet along its reach, and also affect grid azimuths. Moreover, if the local SPCS 83 grid was further modified, then even larger dimension changes can result. Correcting for distortions may require recomputation of coordinates after conversion to ensure original project dimensions and alignment data remain intact. This is particularly important for property and boundary surveys. A less accurate alternative is to compute a fixed shift to be applied to all data points over a limited area. Determining the maximum area over which such a fixed shift can be applied is important. Computing a fixed conversion factor with CORPSCON can be made to within ±1 foot. Typically, this fixed conversion would be computed at the center of a sheet or at the center of a project and the conversions in X and Y from NAD 27 to NAD 83 and from SPCS 27 to SPCS 83 indicated by notes on the sheets or data sets. Since the conversion is not constant over a given area, the fixed conversion amounts must be explained in the note. The magnitude of the conversion factor change across a sheet is a function of location and the drawing scale. Whether the magnitude of the distortion is significant depends on the nature of the project. For example, a 0.5-foot variation on an offshore navigation project may be acceptable for converting depth sounding locations, whereas a 0.1 foot change may be intolerable for construction layout on an installation. In any event, the magnitude of this gradient should be computed by CORPSCON at each end (or corners) of a sheet or project. If the conversion factor variation exceeds the allowable tolerances, then a fixed conversion factor should not be used. Two examples of using Fixed Conversion Factors follow:

(1) Example 1. Assume we have a 1" = 40' scale site plan map on existing SPCS 27 (VA South Zone 4502). Using CORPSCON, convert existing SPCS 27 coordinates at the sheet center and corners to SPCS 83 (US Survey Foot), and compare SPCS 83-27 differences.

	SPCS 83	SPCS 27	SPCS 83 - SPCS 27
Center	N 3,527,095.554	Y 246,200.000	dY = 3,280,895.554
of Sheet	E 11,921,022.711	X 2,438,025.000	dX = 9,482,997.711
NW	N 3,527,595.553	Y 246,700.000	dY = 3,280,895.553
Corner	E 11,920,522.693	X 2,437,525.000	dX = 9,482,997.693
NE	N 3,527,595.556	Y 246,700.000	dY = 3,280,895.556
Corner	E 11,921,522.691	X 2,438,525.000	dX = 9,482,997.691
SE	N 3,526,595.535	Y 245,700.000	dY = 3,280,895.535
Corner	E 11,921,522.702	X 2,438,525.000	dX = 9,482,997.702
SW	N 3,526,595.535	Y 245,700.000	dY = 3,280,895.535
Corner	E 11,920,522.704	X 2,437,525.000	dX = 9,482,997.704

Since coordinate differences do not exceed 0.03 feet in either the X or Y direction, the computed SPCS 83-27 coordinate differences at the center of the sheet may be used as a fixed conversion factor to be applied to all existing SPCS 27 coordinates on this drawing.

(2) Example 2. Assuming a 1" = 1,000' base map is prepared of the same general area, a standard drawing will cover some 30,000 feet in an east-west direction. Computing SPCS 83-27 differences along this alignment yields the following:

	SPCS 83	SPCS 27	SPCS 83 - SPCS 27
West	N 3,527,095.554	Y 246,200.000	dY = 3,280,895.554
End	E 11,921,022.711	X 2,438,025.000	dX = 9,482,997.711
East	N 3,527,095.364	Y 246,200.000	dY = 3,280,895.364
End	E 11,951,022.104	X 2,468,025.000	dX = 9,482,997.104

The conversion factor gradient across this sheet is about 0.2 feet in Y and 0.6 feet in X. Such small changes are not significant at the plot scale of 1" = 1,000'; however, for referencing basic design or construction control, applying a fixed shift across an area of this size is not recommended -- individual points should be transformed separately. If this 30,000-foot distance were a navigation project, then a fixed conversion factor computed at the center of the sheet would suffice for all bathymetric features. Caution should be exercised when converting portions of projects or military installations or projects that are adjacent to other projects that may not be converted. If the same monumented control points are used for several projects or parts of the same project, different datums for the two projects or parts thereof could lead to surveying and mapping errors, misalignment at the junctions and layout problems during construction.

e. Dual grids ticks. Depicting both NAD 27 and NAD 83 grid ticks and coordinate systems on maps and drawings should be avoided where possible. This is often confusing and can increase the chance for errors during design and construction. However, where use of dual grid ticks and coordinate systems is unavoidable, only secondary grid ticks in the margins will be permitted.

f. Global Positioning System (GPS). GPS surveying techniques and computations are based on WGS 84 coordinates, which are highly consistent with NAD 83. Differential (static) GPS surveying techniques are accurate for high order control over very large distances. If GPS is used to set new control points referenced to higher order control many miles from the project, inconsistent data may result at the project site. If the new control is near older control points that have been converted to NAD 83, two slightly different network solutions can result, even though both have NAD 83 coordinates. In order to avoid this situation, locate the GPS base stations on the control in the project area, (i.e., don't transfer it in from outside the area). Use the CORPSCON program to convert the old control from NAD 27 to NAD 83 and use these NAD 83 values to initiate the GPS survey. This allows GPS to produce coordinates that are both referenced to NAD 83 and consistent with the old control.

g. Local project datums. Local project datums that are not referenced to NAD 27 cannot be mathematically converted to NAD 83 with CORPSCON. Field surveys connecting them to other stations that are referenced to NAD 83 are required.

4-7. Horizontal Transition Plan

a. General. Not all maps, engineering site drawings, documents and associated products containing coordinate information will require conversion to NAD 83. To insure an orderly and timely transition to NAD 83 is achieved for the appropriate products, the following general guidelines should be followed:

(1) Initial surveys. All initial surveys should be referenced to NAD 83.

(2) Active projects. Active projects where maps, site drawings or coordinate information are provided to non-USACE users (e.g., NOAA, USCG, FEMA and others in the public and private sector) coordinates should be converted to NAD 83 the next time the project is surveyed or maps or site drawings are updated for other reasons.

(3) Inactive projects. For inactive projects or active projects where maps, site drawings or coordinate information are not normally provided to non-USACE users, conversion to NAD 83 is optional.

(4) Datum notes. Whenever maps, site drawings or coordinate information (regardless of type) are provided to non-USACE users, it should contain a datum note, such as the following:

> THE COORDINATES SHOWN ARE REFERENCED TO NAD *[27/83] AND ARE IN FEET BASED ON THE SPCS *[27/83] *[STATE, ZONE]. DIFFERENCES BETWEEN NAD 27 AND NAD 83 AT THE CENTER OF THE *[SHEET/DATASET] ARE *[dLat, dLon, dX, dY]. DATUM CONVERSION WAS PERFORMED USING THE COMPUTER PROGRAM "CORPSCON." METRIC CONVERSIONS WERE

BASED ON THE *[US SURVEY FOOT = 1200/3937 METER] [INTERNATIONAL FOOT = 30.48/100 METER].

b. Levels of effort. For maps and site drawings the conversion process entails one of three levels of effort:

(1) conversion of coordinates of all mapped details to NAD 83, and redrawing the map,

(2) replace the existing map grid with a NAD 83 grid,

(3) simply adding a datum note.

For surveyed points, control stations, alignment, and other coordinated information, conversion must be made through either a mathematical transformation or through readjustment of survey observations.

c. Detailed instructions.

(1) Initial surveys on Civil Works projects. The project control should be established on NAD 83 relative to NGS National Geodetic Reference System (NGRS) using conventional or GPS surveying procedures. The local SPCS 83 grid should be used on all maps and site drawings. All planning and design activities should then be based on the SPCS 83 grid. This includes supplemental site plan mapping, core borings, project design and alignment, construction layout and payment surveys, and applicable boundary or property surveys. All maps and site drawings shall contain datum notes. If the local sponsor requires the use of NAD 27 for continuity with other projects that have not yet converted to NAD 83, conversion to NAD 27 could be performed using the CORPSCON transformation techniques described in Appendix B.

(2) Active Civil Works Operations and Maintenance projects undergoing maintenance or repair. These projects should be converted to NAD 83 during the next maintenance or repair cycle in the same manner as for newly initiated civil works projects. However, if resources are not available for this level of effort, either redraw the grids or add the necessary datum notes. Plans should be made for the full conversion during a later maintenance or repair cycle when resources can be made available.

(3) Military Construction and master planning projects. All installations and master planning projects should remain on NAD 27 or the current local datum until a thoroughly coordinated effort can be arranged with the MACOM and installation. An entire installation's control network should be transformed simultaneously to avoid different datums on the same installation. The respective MACOMs are responsible for this decision. However, military operations may require NAD 83, including SPCS 83 or UTM metric grid systems. If so, these shall be performed separate from facility engineering support. A dual grid system may be required for such operational applications when there is overlap with normal facilities engineering functions. Coordinate transformations throughout an installation can be computed using the procedure described in Appendix B. Care must be taken when using transformations from NAD 27 with new control set using GPS methods from points remote from the installation. Installation boundary surveys should adhere to those outlined under real estate surveys listed below.

(4) Real Estate. Surveys, maps and plats prepared in support of civil works and military real estate activities should conform as much as possible to state requirements. Since most states have adopted NAD 83, most new boundary and property surveys should be based on NAD 83. The local authorities should be contacted before conducting boundary and property surveys to ascertain their policies. It should be noted that several states have adopted the International Foot for their standard conversion from meters to feet. In order to avoid dual coordinates on USACE survey control points that

have multiple uses, all control should be based on the US Survey Foot, including control for boundary and property surveys. In states where the International foot is the only accepted standard for boundary and property surveys, conversion of these points to NAD 83 should be based on the International foot, while the control remains based on the US Survey foot.

(5) Regulatory functions. Surveys, maps and site drawings prepared in support of regulatory functions should begin to be referenced to NAD 83 unless there is some compelling reason to remain on NAD 27 or locally used datum. Conversion of existing surveys, maps and drawing to NAD 83 is not necessary. Existing surveys, maps and drawings need only have the datum note added before distribution to non-USACE users. The requirements of local, state and other Federal permitting agencies should be ascertained before site specific conversions are undertaken. If states require conversions based on the International foot, the same procedures as described above for Real Estate surveys should be followed.

(6) Other existing projects. Other existing projects, e.g., beach nourishment, submerged offshore disposal areas, historical preservation projects, etc., need not be converted to NAD 83. However, existing surveys, maps and drawings should have the datum note added before distribution to non-USACE users.

(7) Work for others. Existing projects for other agencies will remain on NAD 27 or the current local datum until a thoroughly coordinated effort can be arranged with the sponsoring agency. The decision to convert rests with the sponsoring agency. However, existing surveys, maps and drawings should have the datum note added before distribution to non-USACE users. If sponsoring agencies do not indicate a preference for new projects, NAD 83 should be used. The same procedures as described above for Initial Surveys on Civil Works Projects should be followed.

4-8. Vertical Datums

a. General. A vertical datum is the surface to which elevations or depths are referred to or referenced. There are many vertical datums used within CONUS. The surveyor should be aware of the vertical control datum being used and its practicability to meet project requirements. Further technical details on vertical datums are in Appendix C, Development and Implementation of NAVD 88.

b. NGVD 29. NGVD 29 was established by the United States Coast and Geodetic Survey (USC&GS) 1929 General Adjustment by constraining the combined US and Canadian First Order leveling nets to conform to Mean Sea Level (MSL). It was determined at 26 long term tidal gage stations that were spaced along the east and west coast of North American and along the Gulf of Mexico, with 21 stations in the US and 5 stations in Canada. NGVD 29 was originally named the Mean Sea Level Datum of 1929. It was known at the time that the MSL determinations at the tide gages would not define a single equipotential surface because of the variation of ocean currents, prevailing winds, barometric pressures and other physical causes. The name of the datum was changed from the Mean Sea Level Datum to the NGVD 29 in 1973 to eliminate the reference to sea level in the title. This was a change in name only; the definition of the datum established in 1929 was not changed. Since NGVD 29 was established, it has become obvious that the geoid based upon local mean tidal observations would change with each measurement cycle. Estimating the geoid based upon the constantly changing tides does not provide a stable estimate of the shape of the geoid.

c. NAVD 88. NAVD 88 is the international vertical datum adopted for use in Canada, the United States and Mexico. NAVD 88 is based on gravity measurements made at observation points in the network and only one datum point, at Pointe-au-Pere/Rimouski, Quebec, Canada, is used. The vertical reference surface is therefore defined by the surface on which the gravity values are equal to the control point value. The result of this adjustment is newly published NAVD 88 elevation values for benchmarks (BM) in the NGS inventory. Most Third Order benchmarks, including those of other Federal, state and local government agencies, were not included in the NAVD 88 adjustment. The Federal Geodetic Control Subcommittee (FGCS) of the Federal Geographic Data Committee (FGDC) has affirmed that NAVD 88 shall be the official vertical reference datum for the US. The FGDC has prescribed that all surveying and mapping activities performed or financed by the Federal Government make every effort to begin an orderly transition to NAVD 88, where practicable and feasible. Procedures for performing this transition are outlined in Appendix E.

d. Mean Sea Level datums. Some vertical datums are referenced to mean seal level. Such datums typically are maintained locally or within a specific project area. The theoretical basis for these datums is local mean sea level. Local MSL is a vertical datum based on observations from one or more tidal gaging stations. NGVD 29 was based upon the assumption that local MSL at 21 tidal stations in the US and 5 tidal stations in Canada equaled 0.0000 foot on NGVD 29. The value of MSL as measured over the Metonic cycle of 19 years shows that this assumption is not valid and that MSL varies from station to station.

e. Lake and tidal datums. Some vertical datums are referenced to tidal waters or lake levels. An example of a lake level used as a vertical datum is the International Great Lakes Datum of 1955 (IGLD 55), maintained and used for vertical control in the Great Lakes region of CONUS. These datums undergo periodic adjustment. For example, the IGLD 55 was adjusted in 1985 to produce IGLD 85. IGLD 85 has been directly referenced to NAVD 88 and originates at the same point as NAVD 88. Tidal datums typically are defined by the phase of the tide and usually are described as mean high water, mean low water, and mean lower low water. For further information on these and other tidal datum related terms, the reader is advised to refer to Appendix D (Requirements and Procedures for Referencing Coastal Navigation Projects to Mean Lower Low Water (MLLW) Datum) and EM 1110-2-1003 (Hydrographic Surveying).

f. Other vertical datums. Other areas may maintain and employ specialized vertical datums. For instance, vertical datums maintained in Alaska, Puerto Rico, Hawaii, the Virgin Islands, Guam, and other islands and project areas. Specifications and other information for these particular vertical datums can be obtained from the particular FOA responsible for survey related activities in these areas, or the National Ocean Service (NOS).

4-9. Vertical Datum Transformations

a. General. There are several reasons for USACE commands to convert to NAVD 88.

(1) Differential leveling surveys will close better.

(2) NAVD 88 will provide a reference to estimate GPS derived orthometric heights.

(3) NAVD 88 Height values will be available in convenient form from the NGS database.

(4) Federal surveying and mapping agencies will stop publishing on NGVD 29.

(5) NAVD 88 is recommended by ACSM and FGCS.

(6) Surveys performed for the Federal government will require use of NAVD 88.

The conversion process entails one of two levels of effort:

(1) conversion of all elevations to NAVD 88 and redrawing the map,

(2) adding a datum note based on an approximate conversion.

b. VERTCON. VERTCON is a software program developed by NGS that converts elevation data from NGVD 29 to NAVD 88. Although the VERTCON software has been fully incorporated into the software application package CORPSCON, it will be referred to below as a separate program. VERTCON uses benchmark heights to model the shift between NGVD 29 and NAVD 88 that is applicable to a given area. In general, it is only sufficiently accurate to meet small-scale mapping requirements. VERTCON should not be used for converting benchmark elevations used for site plan design or construction applications. Users input the latitude and longitude for a point and the vertical datum shift between NGVD 29 and NAVD 88 is reported. The root-mean-square (RMS) error of NGVD 29 to NAVD 88 conversion, when compared to the stations used to create the conversion model, is ±1 cm; with an estimated maximum error of ± 2.5 cm. Depending on network design and terrain relief, larger differences (e.g., 5 to 50 cm) may occur the further a bench mark is located from the control points used to establish the model coefficients. For this reason, VERTCON should only be used for approximate conversions where these potential errors are not critical.

c. Datum note. Whenever maps, site drawings or spatial elevation data are provided to non-USACE users, they should contain a datum note that provides, at minimum, the following information:

> The elevations shown are referenced to the *[NGVD 29] [NAVD 88] and are in *[feet] [meters]. Differences between NGVD 29 and NAVD 88 at the center of the project sheet/data set are shown on the diagram below. Datum conversion was performed using the *[program VERTCON] [direct leveling connections with published NGS benchmarks] [other]. Metric conversions are based on *[US Survey Foot = 1200/3937 meters] [International Survey Foot = 0.3048 meters].

4-10. Vertical Transition Plan

a. General. A change in the accepted vertical datum will affect USACE engineering, construction, planning, and surveying activities. The cost of conversion could be substantial at the onset. There is a potential for errors in conversions inadvertently occurring. The effects of the vertical datum change can be minimized if the change is gradually applied over time; being applied to future projects and efforts, rather than concentrated on changing already published products. In order to insure an orderly and timely transition to NAVD 88 is achieved for the appropriate products, the following general guidelines should be followed.

b. Conversion criteria. Maps, engineering site drawings, documents and associated spatial data products containing elevation data may require conversion to NAVD 88. Specific requirements for conversion will, in large part, be based on local usage -- that of the local sponsor, installation, etc. Where applicable and appropriate, this conversion should be recommended to local interests.

c. Newly authorized construction projects. Generally, initial surveys of newly authorized projects should be referenced to NAVD 88. In addition to design/construction, this would include wide-area master plan mapping work. The project control should be referenced to NAVD 88 using conventional or GPS surveying techniques. All planning and design activities should be based upon NAVD 88. All maps and site drawings shall contain datum notes as described below. If the sponsor/installation requires the use of NGVD 29 or some other local vertical reference datum for continuity, the relationship between NGVD 29 and NAVD 88 shall be clearly noted on all maps, engineering site drawings, documents and associated products.

d. Active projects. On active projects where maps, site drawings, or elevation data are provided to non-USACE users, the conversion to NAVD 88 should be performed. This conversion to NAVD 88 may be performed the next time the project is surveyed or when the maps/site drawings are updated for other reasons. Civil works projects may be converted to NAVD 88 during the next maintenance or repair cycle in the same manner as for newly initiated civil works projects. However, if resources are not available for this level of effort, redraw the maps or drawings and add the necessary datum note. Plans should be made for the full conversion during a later maintenance or repair cycle when resources can be made available. Military installations should remain on NGVD 29 or the local vertical datum until a thoroughly coordinated effort can be arranged with the MACOM and installation. An entire installation's control network should be transformed simultaneously to avoid different datums on the same installation. MACOMs should be encouraged to convert to NAVD 88. However, the respective MACOMs are responsible for this decision.

e. Inactive projects. For inactive projects or active projects where maps, site drawings or elevation data are not normally provided to non-USACE users, conversion to NAVD 88 is optional.

f. Work for others. Projects for other agencies will remain on NGVD 29 or the current local vertical datum until a thoroughly coordinated effort can be arranged with the sponsoring agency. Other agencies should be encouraged to convert their projects to NAVD 88, although the decision to convert rests with the sponsoring agency. However, surveys, maps and drawings should have the datum note described below added before distribution to non-USACE users. If sponsoring agencies do not indicate a preference for new projects, NAVD 88 should be used.

g. Miscellaneous projects. Other projects referenced to strictly local datum, such as, beach nourishment, submerged offshore disposal areas, historical preservation projects, etc., need not necessarily be converted to NAVD 88. However, it is recommended that surveys, maps and drawings have a clear datum reference note added before distribution to non-USACE users.

h. Real Estate. Surveys, maps, and plats prepared in support of civil works and military real estate activities should conform as much as possible to state requirements. Many states are expected to adopt NAVD 88 (by statute) as an official vertical reference datum. This likewise will entail a transition to NAVD 88 in those states. State and local authorities should therefore be contacted to ascertain their current policies. Note that several states have adopted the International Foot for their standard conversion from meters to feet. In order to avoid dual elevations on USACE survey control points that have multiple uses, it is recommended that published elevations be based on the US Survey Foot. In states where the International Foot is the only accepted standard for boundary and property surveys, conversion of these elevations to NAVD 88 should be based on the International Foot while the control remains based on the US Survey Foot.

4-11. Mandatory Requirements

Horizontal and vertical datum transition criteria in paragraphs 4-7 and 4-10 are mandatory.